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The Design, Fabrication and Testing of a Prototype Spacecraft Helium Dewar

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The objective of the Prototype Spacecraft Helium Dewar (PSHD) was to demonstrate a conversion of supercritical liquid helium (LHe) to superfluid LHe during a sounding rocket launch of 15 minute duration, by using the vacuum of space as a pump. The PSHD was designed by a team of AFGL engineers and contractors, fabricated and assembled by Wentworth Institute of Technology, an AFGL support contractor.

The design was completed and the flight unit fabricated. Structural qualification tests were conducted on fiberglass/aluminum epoxy joints. Component tests of the Joule Thomson Expander and the counterflow heat exchanger were started, but terminated because of inconsistent results. The design and analysis of the Superfluid liquid helium conversion tank with its associated heat exchanger was completed.

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Preface

The author wishes to thank E. LeBlanc and R. Cabral of Wentworth Institute of Technology, Boston, MA and A. Mironer of Systems Integration Engineering, Lexington, MA for their enthusiasm and drive during design & fabrication of the Prototype Spacecraft Helium Dewar.

Contents

Illustrations

The Design, Fabrication, and Testing of a Prototype Spacecraft Helium Dewar

1. OPERATION OF THE PROTOTYPE SPACECRAFT HELIUM DEWAR (PSHD)

Operation of the PSHD (See Figures 1, 2, and 2a.) was intended as an acceptance test on the ground prior to the rocket borne test.

1.1 Ground Test

For the ground tests, the following sequences were planned:

- Remove experiment door and connect a vacuum pump capable of 250 cubic meters per hour pumping speed.
- Fill the Supercritical LHe (SC LHe) tank and pressurize to 3 atmospheres.
- Fill the Superfluid LHe (SF LHe) tank through the electromagnetic valve no. 2 between the tanks; close valve #2 when T3 ~ 6K; start the vacuum pump.
- Open electromagnetic valve no. 1; precool counterflow heat exchanger to 2.2K in 5 minutes.
- Open electromagnetic valve no. 3; draw vacuum on porous plug line and cool LHe to 1.75K in 30 seconds.
- Energize heater in steps of approximately 1.0 watt per 1 minute steps. Measure boil off rate and temperatures in the conversion tank. Terminate test at 5 watt maximum heater load.

(Received for publication 30 September 1987)

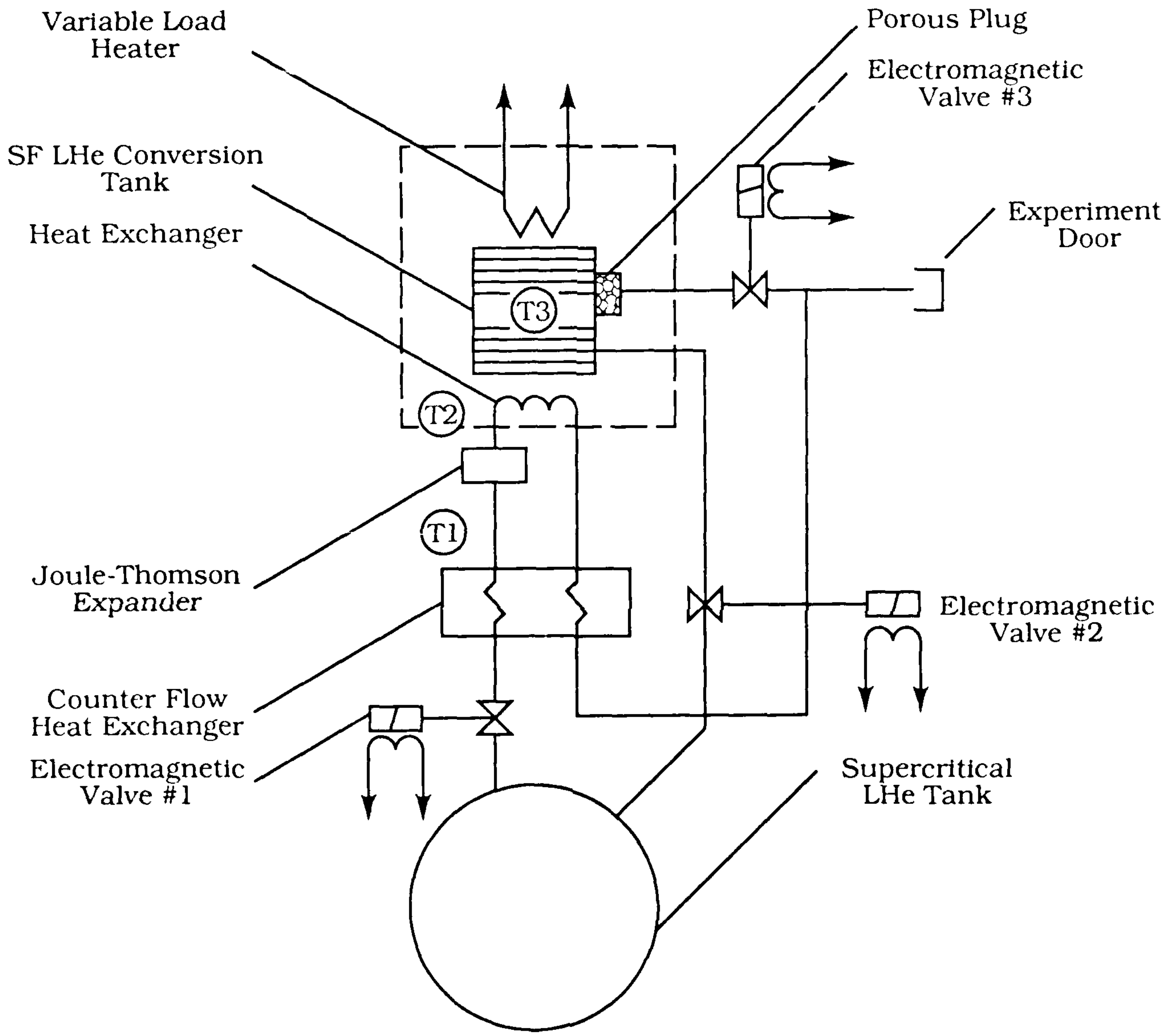

Figure 1. Schematic of PSHD Interior (Shown Without Shields and Structure).

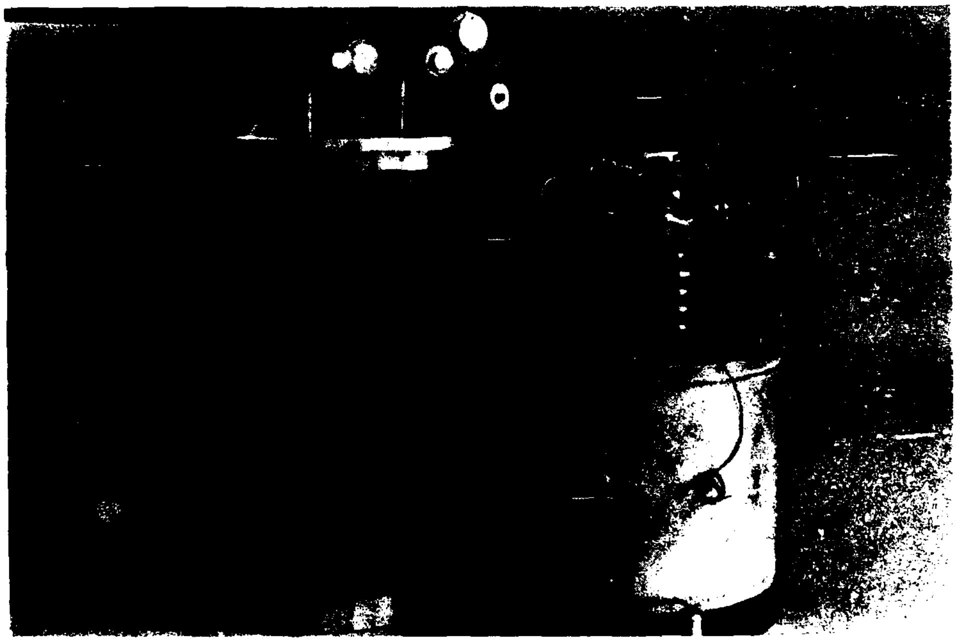

Figure 2. Assembly PSHD Interior.

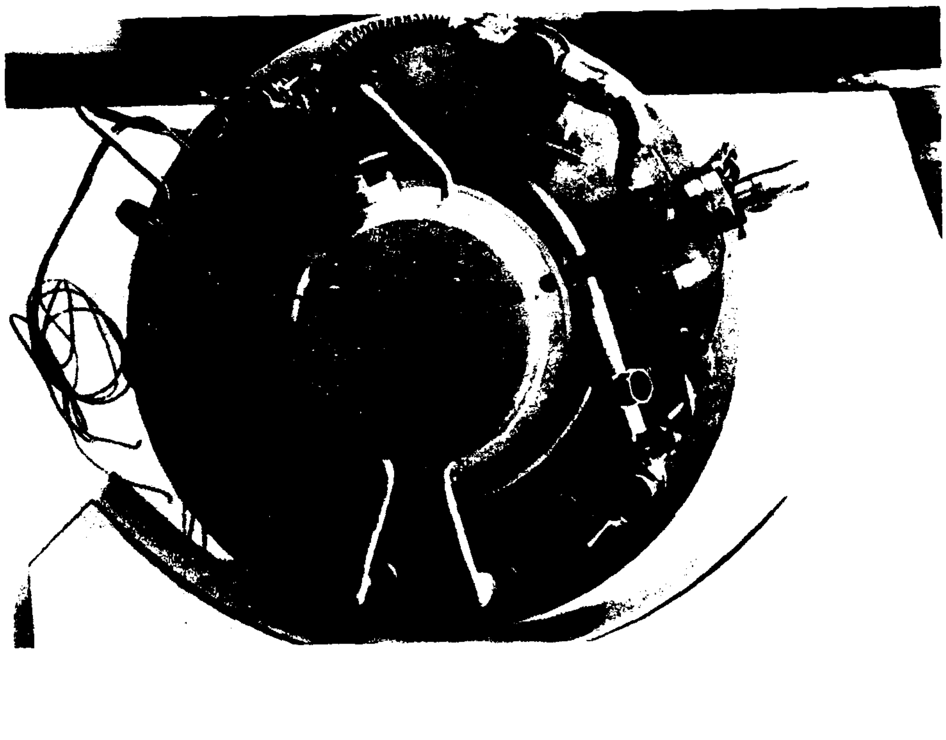

Figure 2a. Assembly, Endview PSHD.
(Note that SFLHe Conversion Tank is located in center of Counter Flow Heat Exchanger).

1.2 Flight Test

For the flight aboard the sounding rocket, the following sequence was planned to meet the times listed below:

T-9 hours	Fill SC LHe tank and pressurize
T-8 hours	Fill SF LHe tank by same method as used in ground test
T-8 to T-3.5 hours	Service Launch Vehicle
T-3.5 hours	Release pressure in both tanks, Top off SC LHe tank
T-10 min.	Release pressure SF LHe tank
T-0	Launch Sounding Rocket
T+100 sec.	Separate payload from launch vehicle
T+105 sec.	Eject experiment door, open value 1 (cool heat exchanger)
T+405 sec.	Open value 3 (convert to SF LHe in Conversion tank)
T+685 sec.	Energize heater at low wattage
T+750 sec.	Increase heater load
T+800 sec.	Increase heater load
T+860 sec.	Increase heater load
T+950 sec.	End of Experiment.

The predicted temperatures at three critical locations are shown in Figure 3 for the flight test sequence of events. See Figure 1 for location of the thermistors.

2. COUNTERFLOW HEAT EXCHANGER

The counterflow heat exchanger (Figures 4 and 4a.) was designed to meet the following thermodynamic requirements.[1]

- Reduce the temperature of the vented vapor from the SC LHe tank to 5.65K at a mass flow rate of 1.1 gram/sec.
- Transfer 10 watts between the inner and outer heat exchanger tubes.
- Maintain Reynolds numbers greater than 2300 to assure turbulent flow and increased heat transfer.

The resultant design utilized a technique similar to a Collins heat exchanger by combining a spirally fluted copper tubing (manufactured by Turbotec, Windsor, CT) inside a Type 304 stainless steel tubing jacket. The spiral flutes acted as the Collins helical windings. Pertinent dimensions are as follows:

- Inner tubing 0.18 inch effective ID
  0.50 inch effective OD at outside diameter of the flutes
  121.00 inches long
- Outer tubing 0.510 ID
  120.00 inches long.

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1. Mironer, A. (1984) private communication.

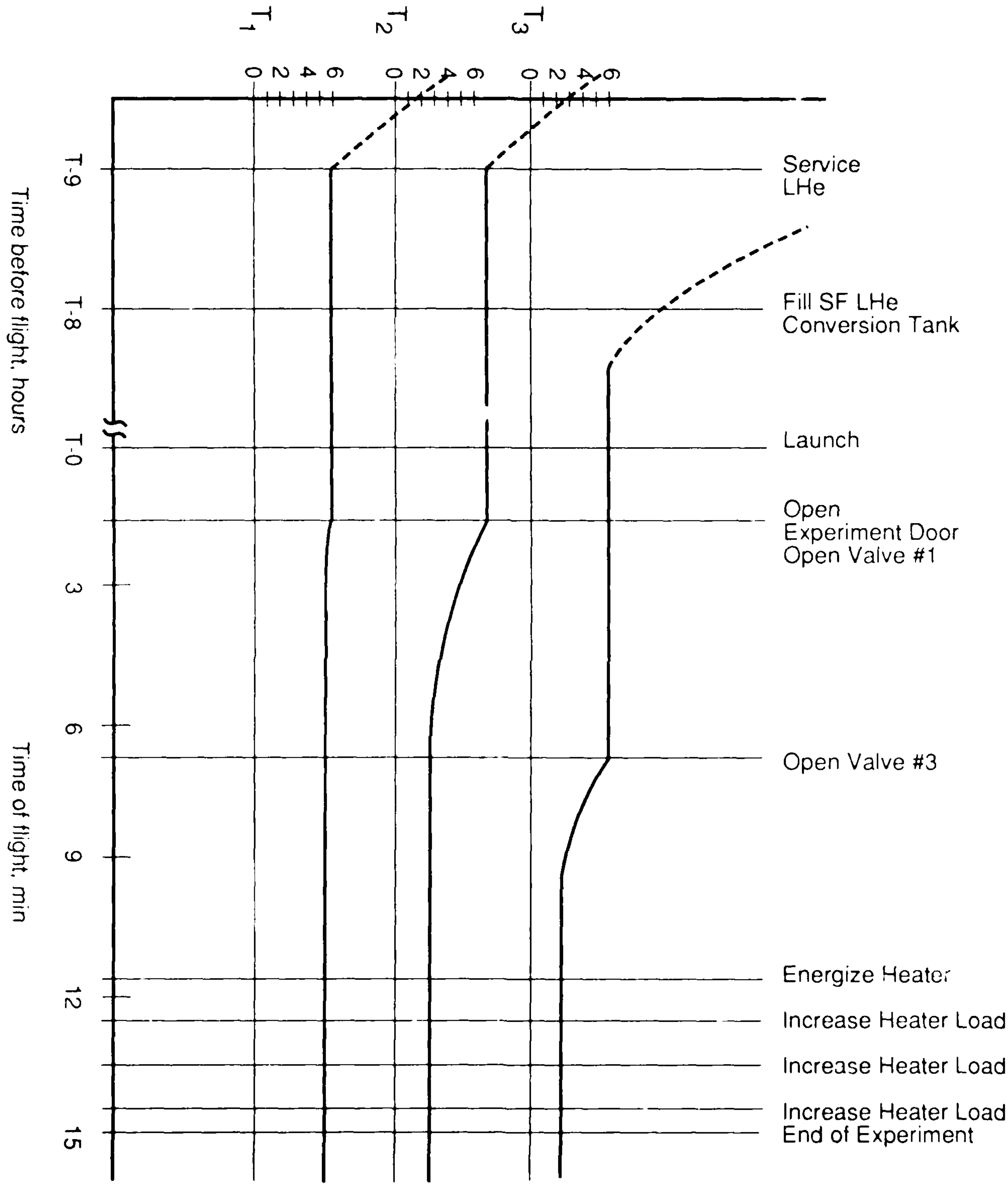

Figure 3. Temperature Profile, Selected Locations.

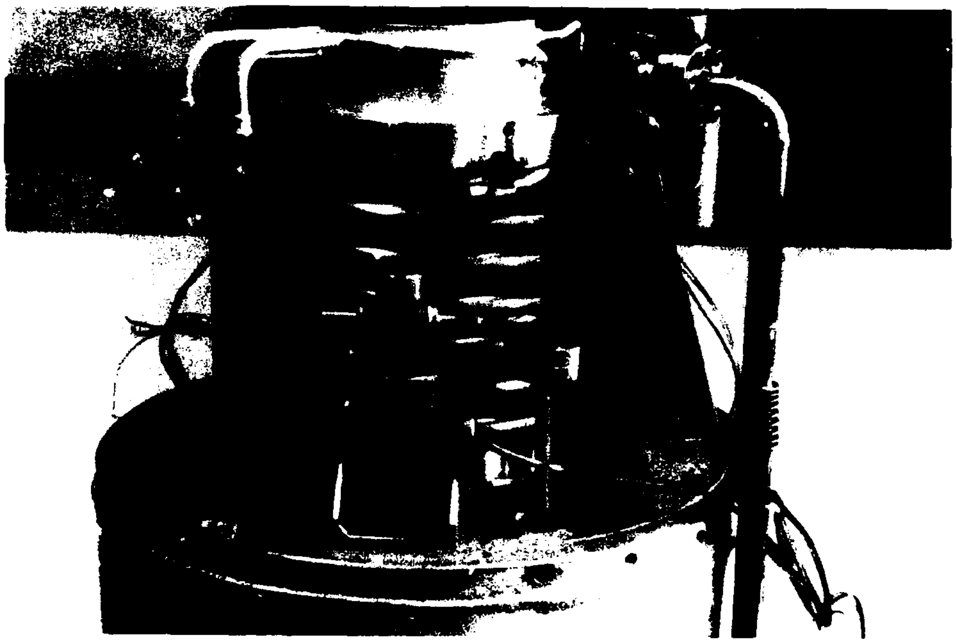

Figure 4. Counterflow Heat Exchanger (CFHX).

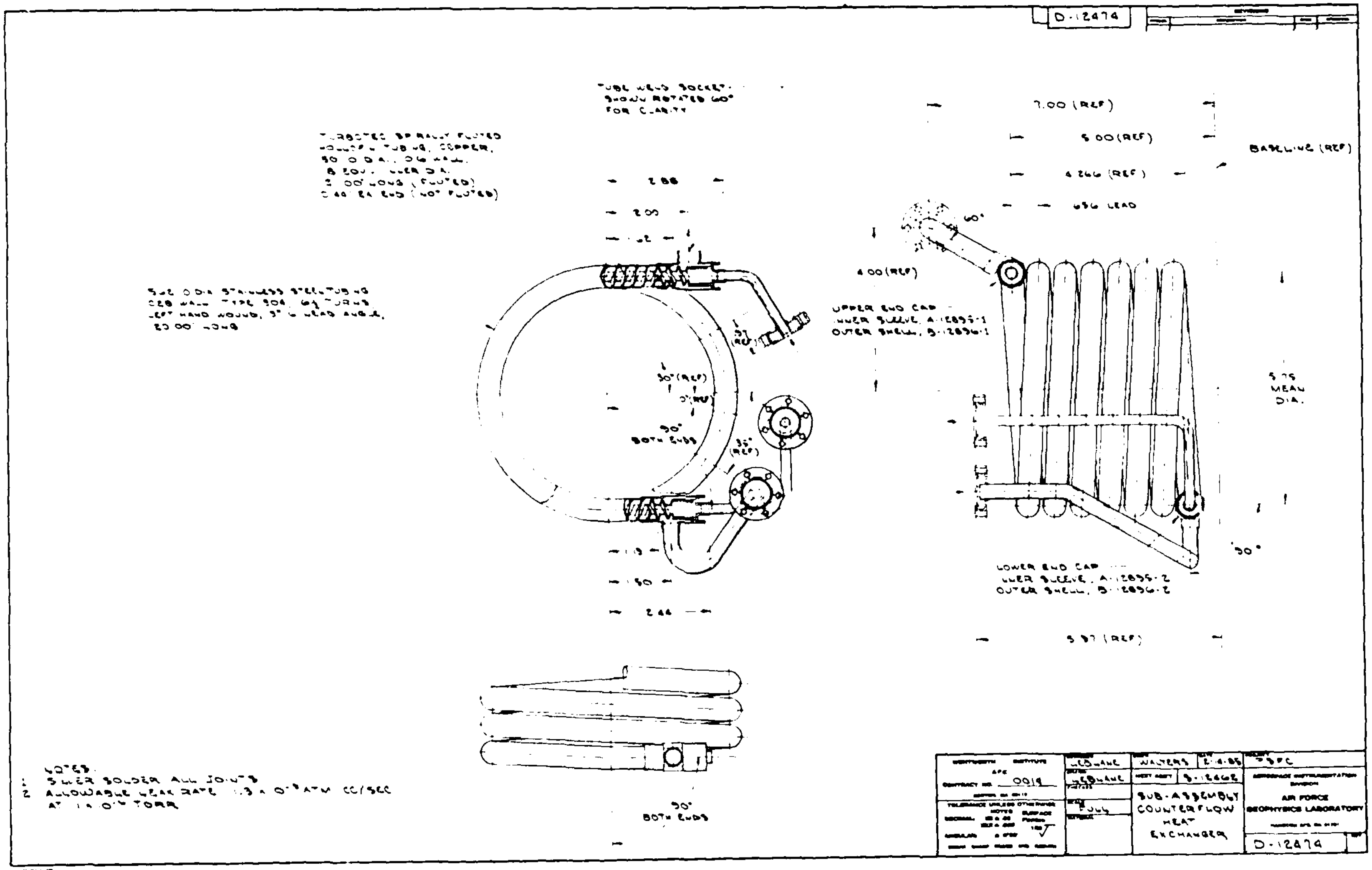

Figure 4a. Sub-Assembly Conterflow Heat Exchanger.

The sub-assembly of the concentric tubes were then formed into a six coil helical assembly of 5.75 inch mean diameter attached with end fittings scaled to the required helium mass flow. The unit was modified to allow acceptance testing in the AFGL test dewar by relocating the end fittings. (See Figure 10).

3. JOULE THOMSON EXPANDER

The Joule Thomson Expander (JTX) shown in Figure 5 was designed to meet the following thermodynamic requirements.[1]

- Reduce the temperature from 5.65K to 2.2K at a mass flow rate of 1.1 gram/sec.

The resultant design utilized principles[2], which considered a series of porous plugs as the throttling resistance to drop the flow pressure and convert the liquid helium vapor to liquid. The JTX porous plug assembly was designed to hold up to four plugs in series. Each porous plug would be in a range between 0.5 and 80 microns porosity. The selection of the porosity was to be determined following CFHX acceptance testing. (See Figure 5 for the location of the JTX in the test dewar.)

4. SUPERFLUID LHE CONVERSION TANK

The conversion tank assembly containing LHe (Figures 6 and 7) was designed to optimize the thermal conductance between the heat exchanger fluid and the fluid within the tank. The assembly consisted of a 1 liter capacity tank of 6061-T6 aluminum containing 100 internal disk fins and a 10-turn heat exchanger coil. Sensors[3] were planned to determine phase changes in the tank.

The assembly was dip brazed as a unit to gain maixmum thermal conductance. The thermal analysis[1,4] indicated a required removal of 3.5 watts during the conversion process, after which the interior temperature would be 2.2 K. The analysis showed that the aluminum fins, 0.005 inches thick spaced at 0.040 inches would result in a temperature difference of 0.3 K between the interior fluid and the fins. The temperature difference between the heat exchanger and the tank interior wall was analyzed to be 0.03 K, resulting in a minimum interior fluid temperature of 2.53 K. This temperature was determined to be low enough to prevent liquid flow through the porous plug during the next phase of the experiment.

The thermodynamic analysis predicted a parasitic heat leak of 51.5 mW to the conversion tank, of which the major heat leak (45 mW) would be the tubing between the tank at 1.8 K and the experiment door at 300 K.

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2. Grier, H.L., Production of Superfluid Helium Using a Joule-Thomson Expander, Beech Aircraft Corp., Boulder, CO.

3. Petrac, D., Gatewood, J., and Mason, P., Sensor for Distinguishing Liquid/Vapor Phases of Superfluid Helium, JPL, Pasadena, CA.

4. Design Considerations for a Proposed Configuration of the Passive Superfluid Concept (1984) Alabama Cryogenic Engineering, Huntsville, AL.

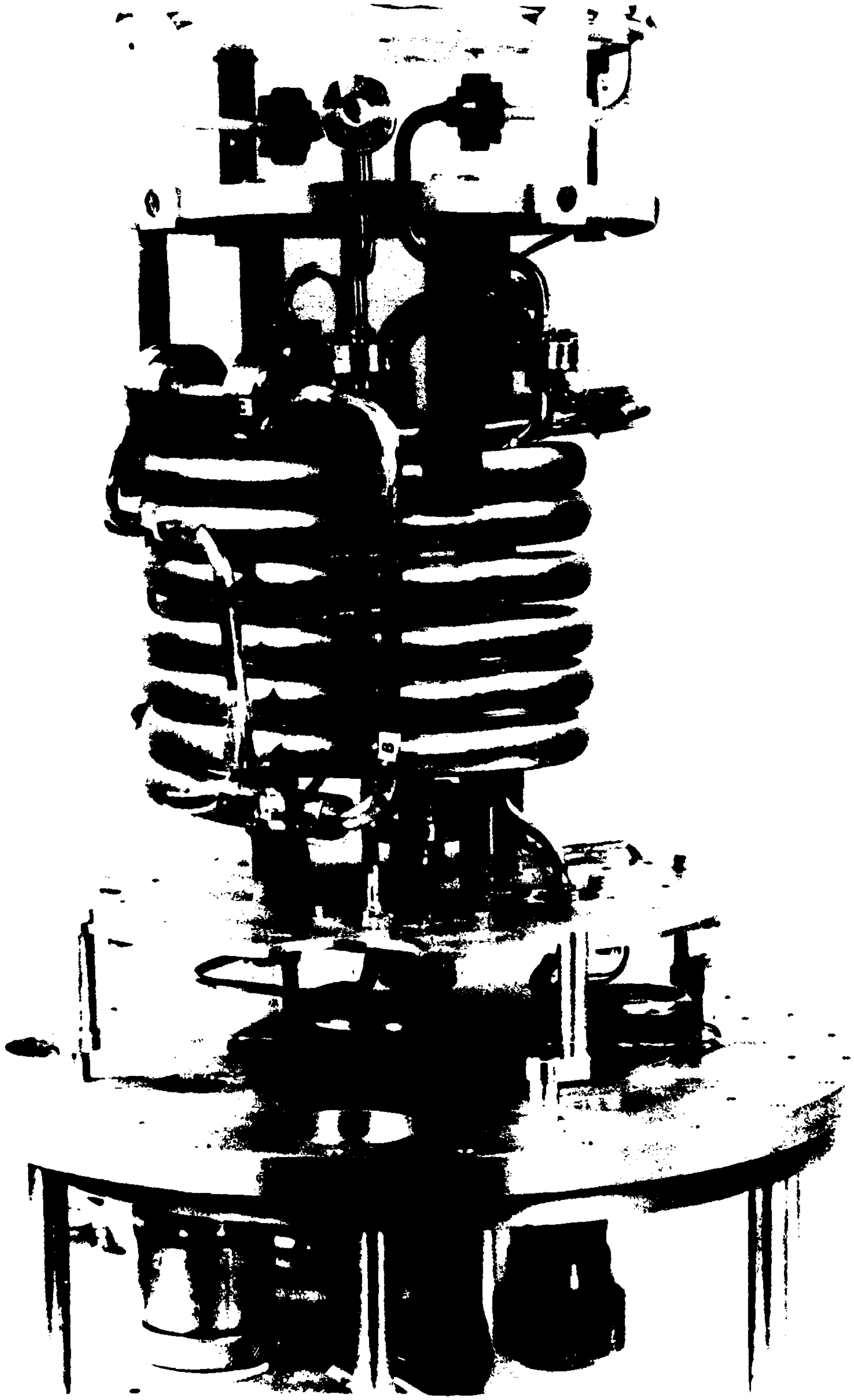

Figure 5. Joule Thomson Expander (JTX) in Acceptance Test Assembly.

Figure 6. SF LHe Container (Thermistor Port Side).

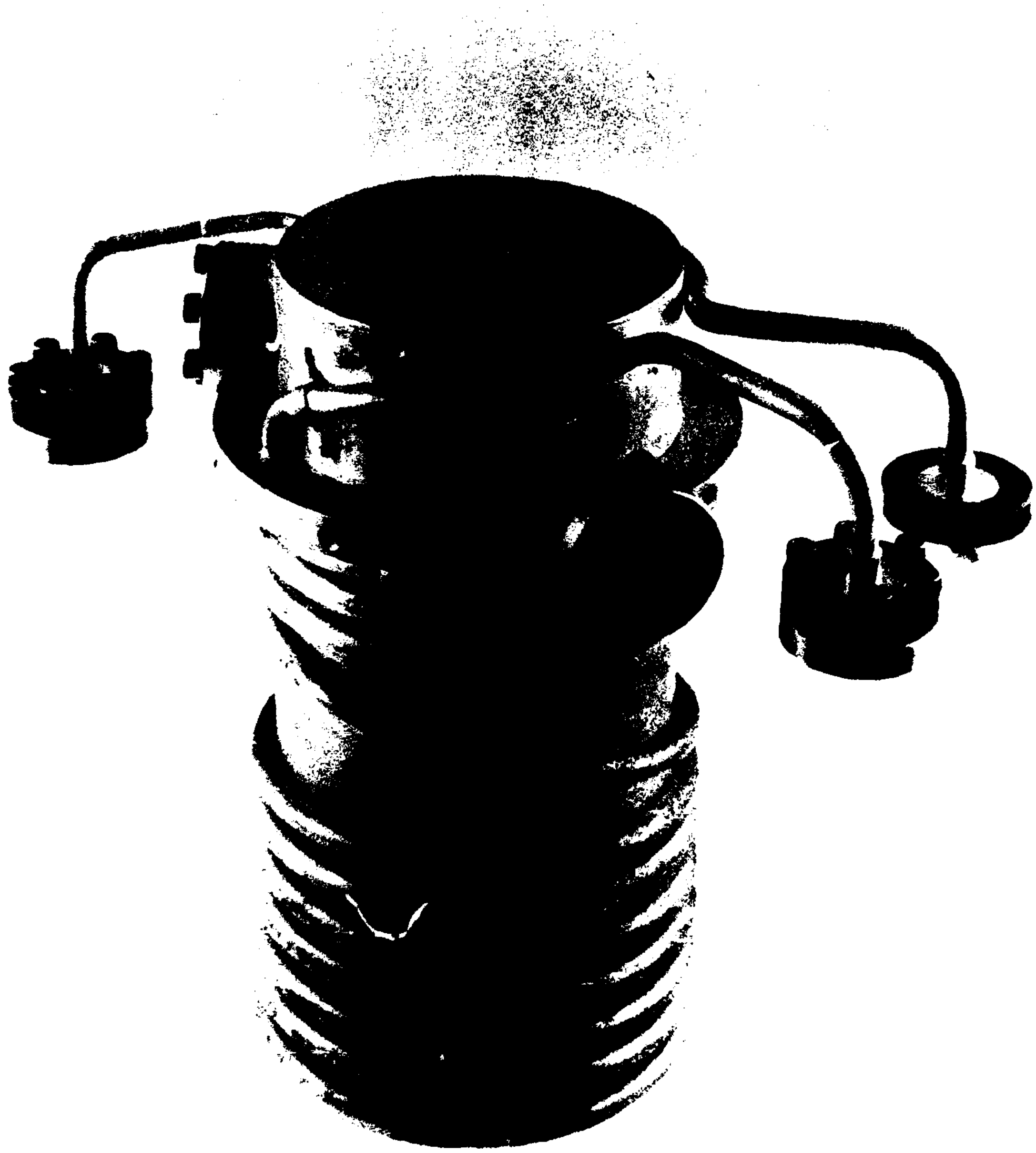

Figure 7. SF LHe Container (Heat Exchanger Connections).

The SF LHe tank (Figure 8) was supported by G-10 fiberglass structural supports mounted directly to the SC LHe container. The structural supports were subjected to structural qualification tests conducted at LHe temperatures which are discussed in Section 5.

5. STRUCTURAL QUALIFICATION TESTS

Qualification tests were conducted during development of the support structure for the SF LHe container to evaluate strength and determine the failure modes of the bonded joints between the fiberglass and aluminum joint rings on a support assembly and a segment of a support assembly. The materials under test were G-10 fiberglass, 6061-T6 aluminum and rings, and Epon resin 828 with Epon curing agent V40 in a 100/82 ratio as a bonding agent. Spacing between the tube and joint rings was maintained during assembly of the epoxy joint at a radial distance of 0.0055 inch by copper wires.

Several support assemblies were tested at liquid helium temperatures and, at the same time subjected to tensile loads, followed by lateral cyclical loads, to determine degradation due to lateral loading. One assembly and a 1-inch wide segment were loaded to failure. The results are shown in Figure 9.

The results were evaluated and found acceptable for the experiment.

6. COMPONENT ACCEPTANCE TESTS

Acceptance tests were started on the assembly of the CFHX and Joule Thomson Expander (Figure 10) in series with a test supercritical LHe dewar. Difficulties in the thermometry and problems with LHe servicing of the cryogen container caused delays in the test phase and prevented progress in the development. Testing was stopped. The flight unit was fabricated, leak tested and assembled when testing was stopped.

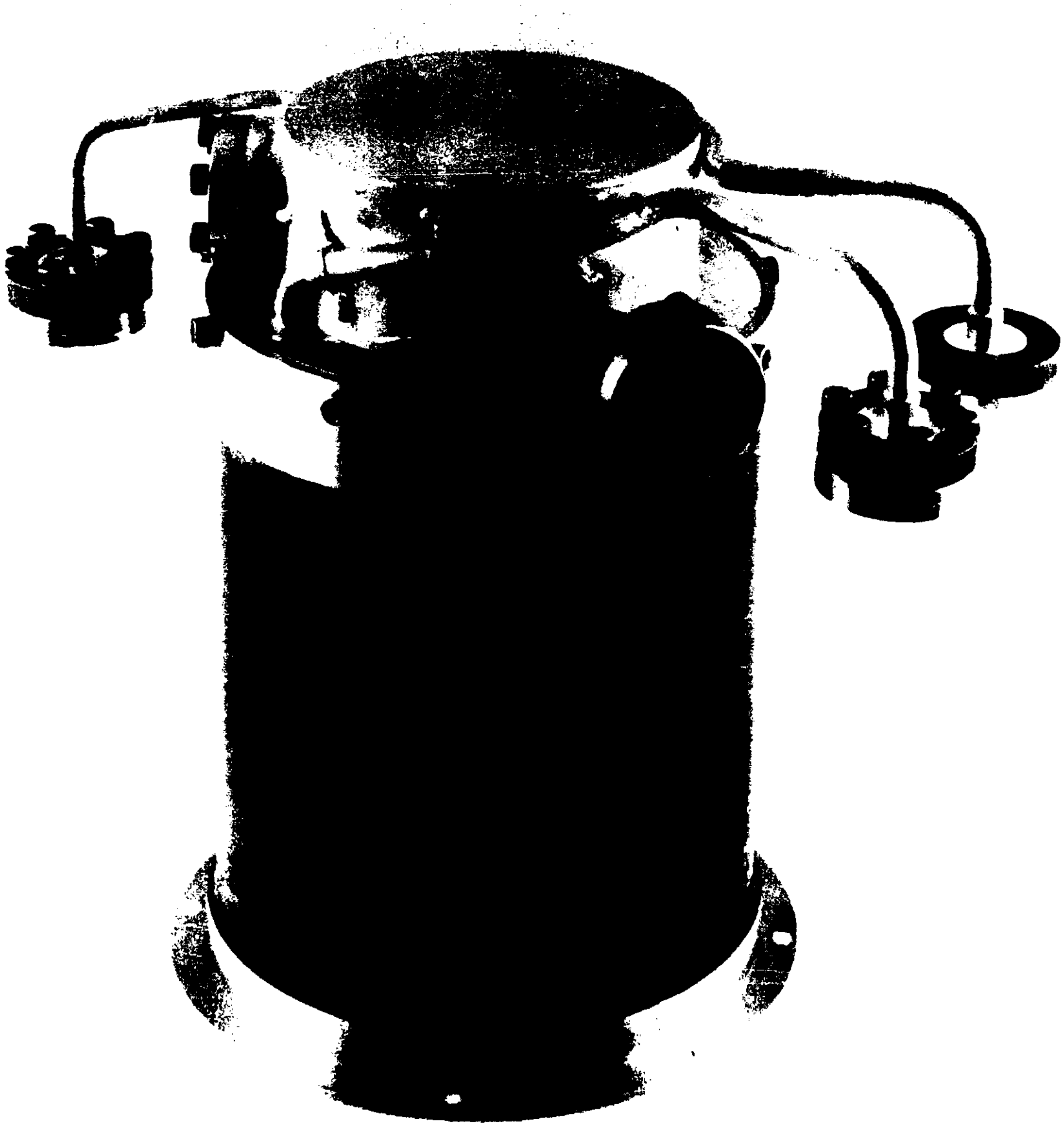

Figure 8. SF LHe Conversion Tank Mounted on Assembly Support.

Specimen	Assembly Support P/N C-12522 Specimen #1	Assembly Support P/N C-12522 Specimen #2	Assembly Support P/N C-12522 Specimen #2	Tube Segment* P/N C-12544 Specimen #1
Area of Bond (sq. in.)	7.56	7.56	7.56	1.0
Load (lbs) Type Load	15925 Tensile	200 Lateral Cyclical @ 15 HZ	10850 Tensile	1330 Tensile
Calculated Stress (psi)	2106	± 159	1435	1330
Failure Mode	None	None	Shear Bond	Shear Bond *Test to failure

Figure 9. Structural Test Results[5].

5. Test Results of the C-12522 Support Structure at Liquid Helium Temperatures (1985) Wentworth Institute of Technology, Boston, MA.

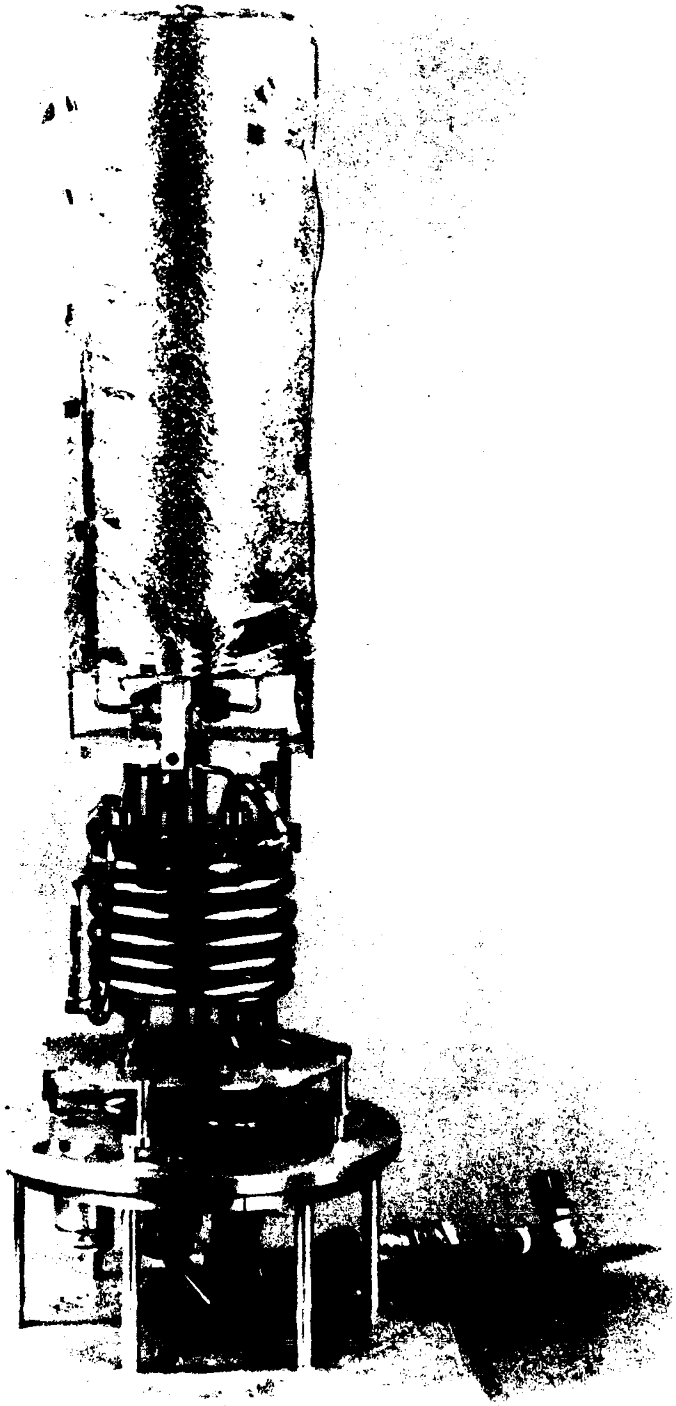

Figure 10. Assembly, Acceptance Test Fixture.

References

1. Mironer, A. (1984) private communication.
2. Grier, H.L., Production of Superfluid Helium Using a Joule-Thomson Expander, Beech Aircraft Corp., Boulder, CO.
3. Petrac, D., Gatewood, J., and Mason, P., Sensor for Distinguishing Liquid/Vapor Phases of Superfluid Helium, JPL, Pasadena, CA.
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5. Test Results of the C-12522 Support Structure at Liquid Helium Temperatures (1985) Wentworth Institute of Technology, Boston, MA.